Multi-carrier Mobile TDMA System with Active Array Antenna

Ryutaro Suzuki, Yasushi Matsumoto and Naokazu Hamamoto
Communications Research Laboratory, MPT
4-2-1 Nukui-Kitamachi, Koganei-shi
Tokyo 184, Japan
Phone: +81-423-21-1211
FAX: +81-423-24-8966

ABSTRACT

A multi-carrier TDMA system is proposed for the future mobile satellite communications which include multi-satellite system. This TDMA system employs the active array antenna in which the digital beam forming technique is adopted to control the antenna beam direction. The antenna beam forming is carried out at the base-band frequency by using the digital signal processing technique. The time division duplex technique is applied for the TDM/TDMA burst format, in order not to overlap transmit and receive timing.

INTRODUCTION

First generation land mobile satellite communication will be introduced with the mechanically tracking antenna and the 4.8 kbps digital voice terminal. For the future mobile satellite communications a multi-satellite system which uses Molniya or Loopus orbit is proposed for effective coverage of the high latitudes[1,2]. In this system, the satellites are moving in a highly elliptic orbit, and the switch over of the satellites is essential for continuous coverage. This will require automated satellite tracking, antenna control etc. Digital signal processing based modulation/demodulation, error correction are already in use in satellite systems. An extension of this technique to perform the antenna control and beam forming operations will be attractive for the future mobile satellite communication system.

This paper proposes a mobile satellite communication system which employs the digital beam forming (DBF) antenna[3] and TDM/TDMA as access techniques. The time division multiplex (TDM) is adopted for the forward link, and time division multiple access (TDMA) is adopted for the return link. The mobile terminal with the active array antenna can track more than two satellites simultaneously which allows easy and uninterrupted switch over of satellite links. However, the disadvantage of the active array antenna is the complexity of the antenna system in which many components such as the low noise amplifiers (LNAs), the high power amplifiers (HPAs) and the diplexers are integrated. In the proposed system, TDM/TDMA with time division duplex technique is adopted for the satellite link between the mobile earth station and HUB station, in order to remove the diplexer from each mobile antenna element.

TDM/TDMA SYSTEM

The simplified configuration of the mobile satellite communication system is shown in Fig. 1. In the earth station, the LNAs and the HPAs are connected to each antenna element. While receiving, the output of LNAs are down-converted and combined in the IF section before delivering to the demodulator. For transmission, the modulated signal is up-converted and sent to each antenna element through its HPA.

The transmit and receive signal power difference for usual satellite communication is more than 100 dB. Therefore, a good diplexer is needed to get high isolation ratio between transmit and receive port for the full-duplex communication system. However, it is quite difficult to get high isolation between the transmitter and the receiver for the active array antenna system in which all RF component should be installed near the antenna elements.

The proposed TDM/TDMA system with time division duplex technique will overcome this difficulty. The features of this system are as follows.

1) Because of alternating operation, isolation between the transmitter and the receiver is needed only to protect the LNAs. Hence, RF switches can be use instead of the diplexers.
2) In a TDMA system, required transmitting power is proportional to the time compression ratio and usually higher than that of SCPC. However, the total power in the proposed system is divided to each HPA of the antenna array element. Hence, low power HPA can be used.
3) Transmitting and receiving frequency can be fixed in the TDMA system. Therefore, there is no need to employ a channel synthesizer.

DIGITAL BEAM FORMING ANTENNA

Fig. 2 shows the configuration of the phased array antenna for the receiver. In the case of the conventional phased array antenna, the antenna beam direction is controlled by using phase shifters which is connected to each antenna element, as shown in Fig. 2a. Therefore, the phase shifters should have low insertion loss. The resolution of the phase control is limited by the control bits of the phase shifters.

In the case of an active array antenna system, the antenna beam forming is carried out at IF stage of the receiver, as shown in Fig. 2b. There is no restriction on the insertion loss of the phase shifters. Also, the multi-beam function is easily available, because another phase shifters with summing port can be added without any loss of the signal quality. Furthermore, in the case of the DBF antenna, the antenna beam can be formed with high flexibility since amplitude compensation is possible.

The features of the DBF antenna are as follows.

1) The signals received at each antenna element are digitized and manipulated to change its phase and amplitude with high resolution. There is no limit to the resolution of the phase and amplitude control.
2) Satellite tracking is carried out by using the software control. Therefore, there is no need to prepare a special equipment for the satellite tracking function.
3) The multi-beam function can be achieved by adding calculation routine for another beam forming.
4) Difference of characteristics among each RF components can be compensated easily by using software without any dedicated circuitry.

For the land-mobile satellite communications, the size of the antenna system should be small enough to install on the roof of the vehicle. Therefore, the LNAs and HPAs in a DBF antenna system should be integrated just under the antenna elements, and high integration technique is required to combine all units. At present, required complexity of LSI is not available. Further developments are necessary for the digital LSI technique to realize such DBF antenna system. Then, the functions such as the antenna control, beam forming, modulation/demodulation, coding/decoding can be performed using digital signal processing.

LINK BUDGET FOR PROPOSED SYSTEM

In Japanese ETS-V satellite, a similar TDM/TDMA system has been designed. Table 1 presents a typical link budget for the system. For the calculation of the link budget, following conditions were assumed.

1) Maximum satellite power is used for the TDM link.
2) 4.8 kbps digital voice is used for this communication system.
3) Seven element active array antenna is adopted for the mobile antenna, because of its simplicity.
4) Separate antennas are used for transmission and reception respectively to reduce the feeder loss.

In Table 1, G/T for the mobile earth station is estimated to be -12 dBK at an elevation angle of 45 degrees. For this case, link budget estimate shows 60 dBHz of the carrier to noise power ratio (C/No). Therefore, the transmission rate of up to 64 kbps is available for the forward link. This means ten voice channels are available for the link. For the return link, assuming same transmission rate as the forward link, the total transmitting power estimate of the mobile terminal is 25 W. This value is divided among each HPA connected to antenna array elements. As a result, 4 W HPA will have sufficient output power for each antenna array element.

Table 1. Link budget of the TDM/TDMA system

Forward link (TDM)		
satellite TX (ETS-V)		
HPA output power	11.0	dBW
Feeder & DIP loss	3.9	dB
Antenna gain	23.5	dBi
Satellite EIRP	30.6	dBW
Propagation loss	187.7	dB
Mobile station RX (Active array antenna)		
Antenna array element gain	4.0	dBi
System noise temperature	240	K
Antenna element G/T	-19.8	dBK
Number of array elements	7	
Coupling loss	1.0	dB
Total G/T	-12.4	dBK
Down-link C/No	59.1	dBHz
Total C/No	59.1	dBHz
Required C/No (64 kbps)	55.0	dBHz
Link margin	4.1	dB
Return link (TDMA)		
Mobile station TX (Active array antenna)		
Antenna array HPA output (3.5 W)	5.4	dBW
Antenna element gain	4.0	dBi
Coupling loss	1.0	dB
Total antenna gain	11.5	dBi
Total TX power (24.5 W)	13.9	dBW
Total EIRP	25.4	dBW
Propagation loss	188.3	dB
Satellite RX (ETS-V)		
Antenna gain	24.0	dBi
Feeder & DIP loss	3.1	dB
Satellite G/T	-5.5	dBK
Up-link C/No	60.2	dBHz
Total C/No	60.0	dBHz
Required C/No	55.0	dBHz
Link margin	5.0	dB

For Molniya, Tundra, or Loopus orbits the elevation angles at the mobile terminals are in excess of 50 degrees at all times. For such elevation angles shadowing is minimal and required fade depth is 4 dB and 10 dB for 95% and 99% link availability[5]. A dedicated fade margin of 5 dB and moderate adaptive FEC (e.g. RCPC constraint length 7, concatenated coding etc) with interleaving can easily provide highly reliable link.

TDM/TDMA FRAME FORMAT

An example of TDM/TDMA frame format is shown in Fig. 3. The short frame length results in low frame efficiency because of its overhead of the guard time, synchronization and identification of the burst signals. On the other hand, the delay time of the demodulation is proportional to the frame length. Therefore, a frame length of 120 mS is selected to minimize the delay time.

In addition, the time division duplex mode is employed for the mobile terminal. Hence, the TDM and TDMA frame formats should be selected such that transmit and receive timing of each mobile earth stations do not overlap. Each mobile earth station receives the link control data and the voice data from satellite/HUB station in the TDM frame, and transmit the voice data to the satellite/HUB station using the TDMA frame format. The overlap between the transmit and receive voice signal is avoided by changing the order of the burst signal of the voice data in the TDMA frame. However, it is possible that one mobile station transmits the signal at the same time as the link control signal is being received. This collision will cause the loss of link control information. In order to avoid this problem, the link control signal is transmitted twice in the TDM frame.

There is a allocation of 0.5 mS of guard time between the burst signals and 5.5 mS for the initial acquisition. Each Mobile earth station transmit the initial acquisition signal with predicted timing calculated from the position data of the earth station.

SYSTEM CONFIGURATION

Fig. 4 shows the configuration of the mobile earth station. It is interesting to observe that the antennas, which consist of seven elements of the microstrip disk antenna are separated for the transmitter and the receiver. Therefore, there is no need to protect the low noise amplifier from the transmitting power damage.

Also, transmission frequency is fixed for the TDMA system, and channel synthesizer is not needed. To eliminate the IF section, direct L-band modulation can be considered.

At the receive side, the LNA outputs are down-converted using common local carrier, and fed to the beam forming circuit. Received signals from each of seven antenna elements are amplitude/phase compensated before being summed. Therefore, the signal to noise power ratio of the received signal is improved at the output of the beam forming circuit. Finally, this signal is stored in the frame buffer memory, and demodulated.

CONCLUSIONS

The authors have proposed the multi-carrier TDMA system with active array antenna for the future mobile satellite communications. An example of TDM/TDMA system and link budget calculation is given. An analysis of the signal search algorithm in low C/N condition is left as a subject for further studies.

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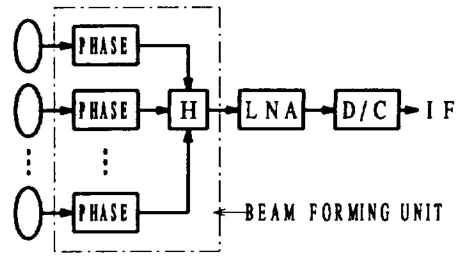
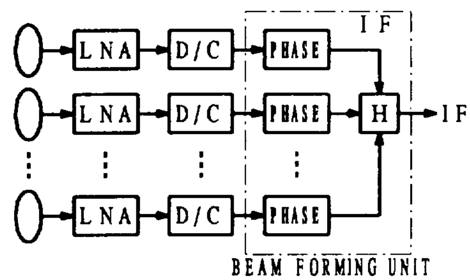
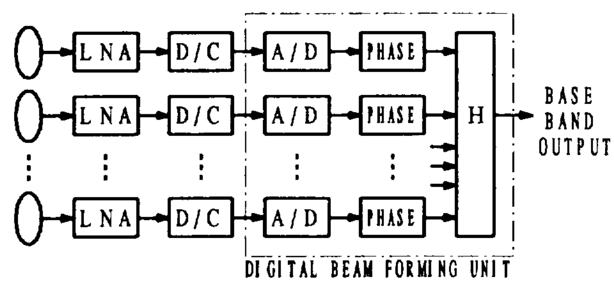


a) Conventional phased array antenna



Active array with IF phase shifter



DBF array antenna

b) Active array antenna

Fig. 2. Configuration of the phased array antenna

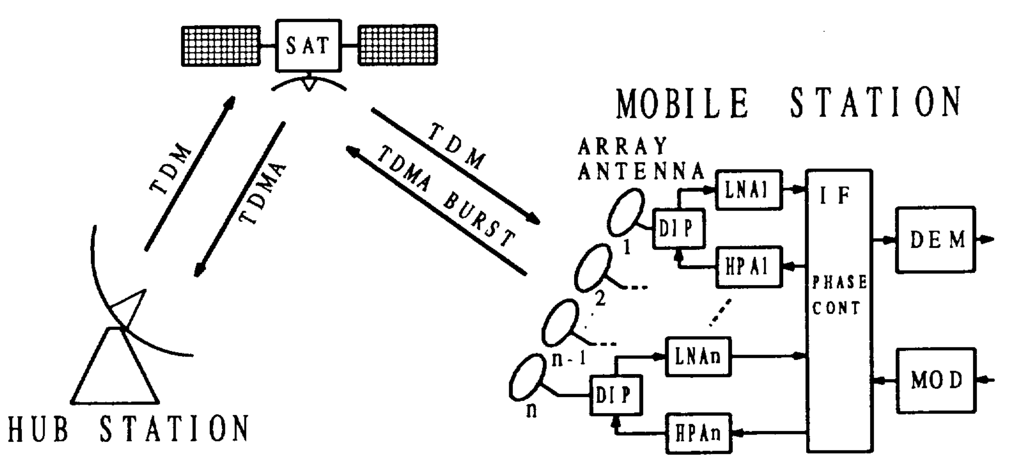


Fig. 1. Simplified configuration of TDM/TDMA satellite communication system

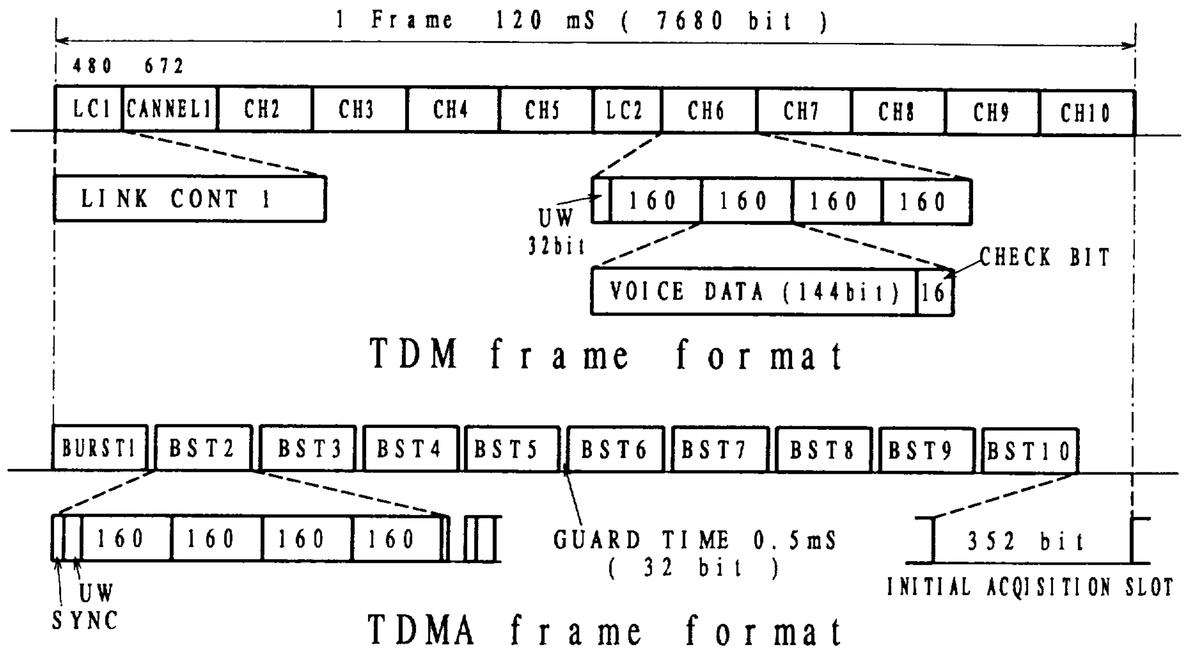


Fig. 3. Example of TDM/TDMA frame format (without FEC)

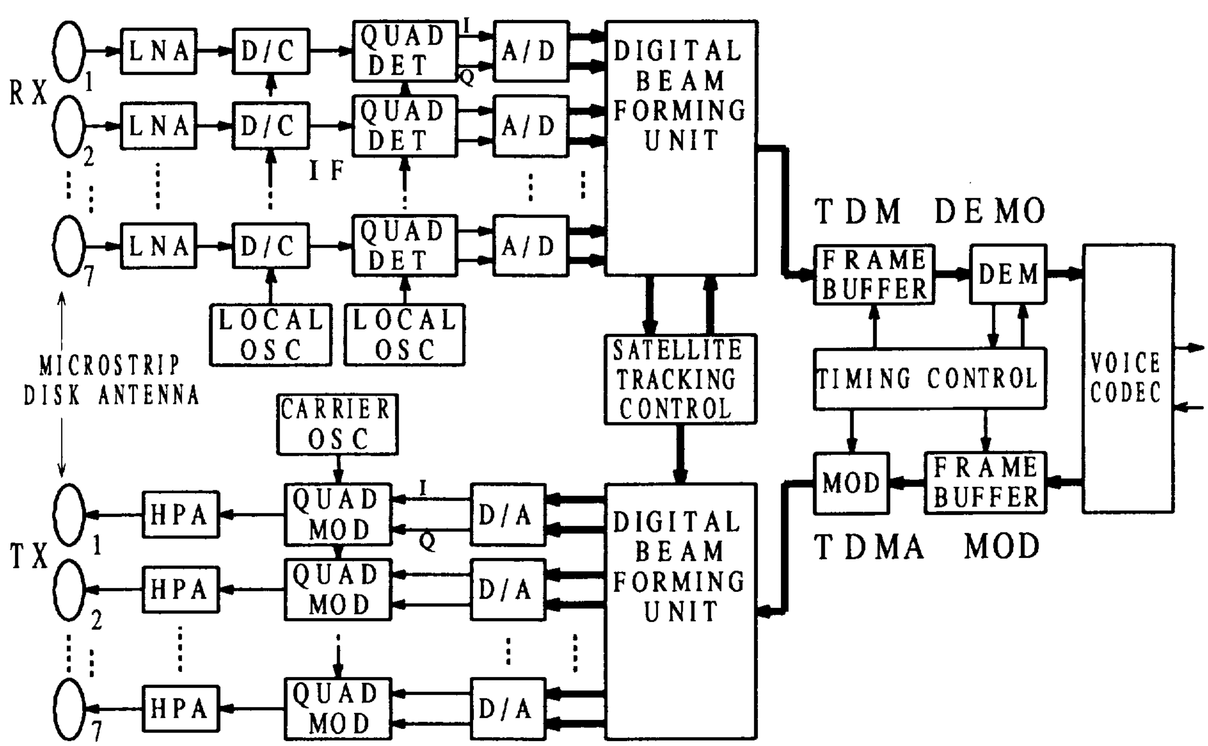


Fig. 4. Configuration of TDM/TDMA mobile earth station